

Regenerative Simulation of Stochastic Petri Nets with Discrete and Continuous Timing

Rob Jones

ASRC Aerospace Corporation
P.O. Box 183, Williamsburg, VA 23187
robert.jones@akspace.com

Gianfranco Ciardo

College of William & Mary, Dept. of Computer Science
P.O. Box 8795, Williamsburg, VA 23187
ciardo@cs.wm.edu

Abstract

We present a regenerative simulation method applicable to a special class of non-Markovian stochastic Petri net (SPN) that may be useful in practice for constructing and solving performance models. Introduced in [1], this special SPN is called a phased delay Petri net (PDPN) and was conceived to allow efficient numerical analysis while increasing the modeling fidelity. The PDPN permits phase-type firing delays in both discrete and continuous time simultaneously in the same model. However, exact numerical analysis requires that the discrete-time transitions be synchronized when active. We propose here, instead, a new regenerative simulation technique that offers efficient analysis of PDPNs where numerical solution by exact means or other (known) types of regenerative simulation is too difficult.

1. Introduction

As far as we know, simulation of phase-type models has not been specifically addressed before in the literature—not surprisingly, since phase-type distributions are typically introduced to allow an exact numerical solution. One might ask: Why simulate models with phase-type probability distributions when completely general distributions could be sampled instead? Well, regenerative simulation of PDPNs is an interesting idea for at least two reasons. First, simulating a PDPN is easy and efficient, as only exponential random variables and uniform random variables between zero and one are needed; the former are used to determine the time until the next phase-change event in continuous time (this time is a constant τ for discrete-time delays), the latter are used to select the next phase from the stochastic transition matrix associated with each phase-type distribution. The second reason is that, unlike general SPNs, PDPNs possess properties that aid the identification of hidden regenerative structures and easier determination of regeneration times.

2. Background

We adopt the standard SPN definitions: a bipartite graph with two finite sets of nodes, places, P , and transitions, T , which are connected by directed arcs. Places can contain tokens and the marking $M \in \mathbb{N}^{|P|}$ denotes the number of tokens in each place. Marking changes occur when an enabled transition fires, possibly after delaying a (finite, random) amount of time, thereby removing tokens from input places and depositing tokens in output places according to the arc multiplicities. We assume that the transition selected to fire is the one with the minimum remaining firing time (RFT) over all enabled transitions.

The marking process, $\{M(\theta) : \theta \geq 0\}$, observes the marking evolution over time. This gives rise to an underlying stochastic process amenable to mathematical analysis. Among the most convenient stochastic processes are the discrete-time Markov chain (DTMC), which results when firing delays are geometrically distributed, and the continuous-time Markov chain (CTMC), which results when firing delays are exponentially distributed. When the applicability of these Markovian models to more complex and realistic systems is questionable, other extensions attempt to incorporate non-Markovian behavior. However, the complexity of exact solutions to non-Markovian processes oftentimes limits the practical usefulness to problems with small dimensions unless simulation is employed.

A phase-type random variable is defined as the time to absorption of a given Markov chain with at least one absorbing state. We let `ph_int` and `ph_real` refer to phase-type random variables (or distributions) in discrete and continuous time, respectively. An absorbing CTMC (DTMC) is used to define a `ph_real` (`ph_int`) distribution, which includes initial state probabilities to be used when sampling the distribution. We let T_{real} denote the set of `ph_real` transitions and T_{int} , the set of `ph_int` transitions. The set T_{zero} contains the immediate transitions with zero firing delays, and $T = T_{\text{real}} \cup T_{\text{int}} \cup T_{\text{zero}}$.

In general, the state of an SPN model is the current

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Corporation. Research Division, G. S.
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S. Shedler, 1991 *Regenerative Stochastic Simulation* G.S. Shedler, **An Introduction to the Regenerative Method
for Simulation Analysis** M. A. Crane, A. J. Lemoine, 1977 The purpose of this report is to provide an introduction to the
regenerative method for simulation analysis The simulations are simulations of stochastic systems i e systems with random
elements The regenerative approach leads to a statistical methodology for analyzing the output of those simulations which
have the property of starting afresh probabilistically from time to time The class of such simulations is very large and very
important including simulations of a broad variety of queues and queueing networks inventory systems inspection
maintenance and repair operations and numerous other situations **Regenerative Stochastic Simulation:**

Simultaneous Trigger Events G. S. Shedler, 1992 **Regeneration and Networks of Queues** Gerald S.
Shedler, 2012-12-06 Networks of queues arise frequently as models for a wide variety of congestion phenomena Discrete
event simulation is often the only available means for studying the behavior of complex networks and many such simulations
are non Markovian in the sense that the underlying stochastic process cannot be represented as a continuous time Markov
chain with countable state space Based on representation of the underlying stochastic process of the simulation as a gen
eralized semi Markov process this book develops probabilistic and statistical methods for discrete event simulation of
networks of queues The emphasis is on the use of underlying regenerative stochastic process structure for the design of
simulation experiments and the analysis of simulation output The most obvious methodological advantage of simulation is
that in principle it is applicable to stochastic systems of arbitrary complexity In practice however it is often a decidedly
nontrivial matter to obtain from a simulation information that is both useful and accurate and to obtain it in an efficient
manner These difficulties arise primarily from the inherent variability in a stochastic system and it is necessary to seek
theoretically sound and computationally efficient methods for carrying out the simulation Apart from implementation
considerations important concerns for simulation relate to efficient methods for generating sample paths of the underlying
stochastic process the design of simulation experiments and the analysis of simulation output **ACM Transactions on
Modeling and Computer Simulation** ,2001 *Distributed Computer and Communication Networks: Control,
Computation, Communications* Vladimir M. Vishnevskiy, Konstantin E. Samouylov, Dmitry V. Kozyrev, 2021-01-04 This book
constitutes the refereed proceedings of the 23rd International Conference on Distributed and Computer and Communication

Networks DCCN 2020 held in Moscow Russia in September 2020 Due to the COVID 19 pandemic the conference was held online The 43 papers were carefully reviewed and selected from 167 submissions The papers are organized in the following topical sections computer and communication networks and technologies analytical modeling of distributed systems and distributed systems applications Research in Progress ,1982

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Table of Contents Regenerative Stochastic Simulation

1. Understanding the eBook Regenerative Stochastic Simulation
 - The Rise of Digital Reading Regenerative Stochastic Simulation
 - Advantages of eBooks Over Traditional Books
2. Identifying Regenerative Stochastic Simulation
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Regenerative Stochastic Simulation
 - User-Friendly Interface
4. Exploring eBook Recommendations from Regenerative Stochastic Simulation

- Personalized Recommendations
- Regenerative Stochastic Simulation User Reviews and Ratings
- Regenerative Stochastic Simulation and Bestseller Lists
- 5. Accessing Regenerative Stochastic Simulation Free and Paid eBooks
 - Regenerative Stochastic Simulation Public Domain eBooks
 - Regenerative Stochastic Simulation eBook Subscription Services
 - Regenerative Stochastic Simulation Budget-Friendly Options
- 6. Navigating Regenerative Stochastic Simulation eBook Formats
 - ePub, PDF, MOBI, and More
 - Regenerative Stochastic Simulation Compatibility with Devices
 - Regenerative Stochastic Simulation Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Regenerative Stochastic Simulation
 - Highlighting and Note-Taking Regenerative Stochastic Simulation
 - Interactive Elements Regenerative Stochastic Simulation
- 8. Staying Engaged with Regenerative Stochastic Simulation
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Regenerative Stochastic Simulation
- 9. Balancing eBooks and Physical Books Regenerative Stochastic Simulation
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Regenerative Stochastic Simulation
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Regenerative Stochastic Simulation
 - Setting Reading Goals Regenerative Stochastic Simulation
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Regenerative Stochastic Simulation

- Fact-Checking eBook Content of Regenerative Stochastic Simulation
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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